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Status of the Low-Energy Linac 200-MHz RF Stations

Committee members:
Proton Source Department - C. W. Schmidt, R. Webber, E. McCrory, L. Allen, A. Moretti, M. Popovic, L. Wahl, K. Quinn, J. Walters;
RF Department - R. Pasquinelli, J. Reid

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Thanks for carrying this forward. This is an important issue that requires attention.

I certainly would like to find a solution that is practical and eliminates our reliance on the 7835's.

John Marriner
September 6, 2001

We discussed strategies to deal with the demise of production of F1123 switch tubes used in the 200-MHz Linac modulators. We also acknowledged that there is no guarantee as to the future of the 7835 RF power amplifier tube.

Options cited include:
1) New linear modulator design sans F1123 tubes with continued reliance on the 7835 RF power amplifier tube.
2) New bang-bang modulator design with continued reliance on the 7835 and modified RF driver to permit RF control.
3) Complete new 200-MHz power system sans 7835.
4) New low energy Linac accelerating structures operating at higher frequency where existing klystron amplifier designs could be applied.

It should be noted that any of these options will be long lead time, high cost projects and will require dedicated manpower to execute.

Robert Webber
April 20, 2001

Content

Introduction

Last year the only remaining manufacturer of a high power tube used in the five 200-MHz Linac RF systems announced that they are discontinuing manufacture of that tube. This prompted the Proton Source Department to form a RF study committee to consider the significance of this event and other vulnerabilities that may impact future Linac operation.

This report describes the present status of the five low-energy Linac 200-MHz RF stations with regard to availability and reliability of major components. An attempt has been made to describe possible solutions (or non-solutions) and to indicate some of the complexity and interplay between those solutions.

For the problem at hand, the discontinuance of this one particular tube, an acceptable solution plan must be identified and designed in detail in the near future. As explained herein, <u>the time scale for implementing a solution is five years</u>; beyond that time there is considerable risk of finding ourselves with a non-maintainable Linac and no High Energy Physics program at Fermilab!

<u>200-MHz RF System Overview</u>

The low-energy Linac is comprised of five 200-MHz drift-tube cavities (Tanks) to accelerate beam to 116 MeV. For thermal and operational stability, the RF is pulsed to the cavities on every 15-Hz cycle whether beam is accelerated or not. The RF pulse length is ~350 μsec with a 150 μsec flattop, giving a duty factor of 0.3 to 0.5%. Tank 1 requires 2 MW and Tanks 2-5 require 4.5-5 MW each of RF pulsed power to accelerate beam. For each tank, there is one RF power station consisting of a three-stage driver and a final power amplifier (PA). Figure 1 shows a block diagram of a RF power system.

A 200-MHz RF reference signal, derived from a stable 800-MHz oscillator, is distributed to each low-energy station and serves as the driver input. This is amplified to 400 watts by a solid-state amplifier and then to 4 kW by a 7651 tube amplifier. The 7651 powers the grid of the driver output stage, a 4616 tube that provides 175-kW pulsed RF to the final PA grid circuit.

The final PA is a five megawatt 7835 power tube. The 7835 requires five volts at 7000 A for filament power. This is provided by a multi-phase rectifier unit on a step-down transformer following an 825-VAC, 56-A, 80-kW GE Inductrol variable transformer for power regulation. A high power modulator controls the pulsed voltage applied to the 7835 anode. The input voltage is supplied from a 50-kV, multi-ampere high voltage transformer and SCR rectifier system that charges 36 microfarads of capacitance. Three parallel F1123 "switch" tubes operate as series-pass regulators between the capacitor bank and the modulator output that connects to the 7835 anode. Typical system operation requires the modulator to supply 30 kV at >300 A to the PA. The "switch" tubes are controlled by a solid-state mosfet amplifier and two 6544 power tubes. An optical-fiber link provides communication between the low-level RF control circuitry and the mosfet amplifier to regulate the cavity RF voltage and compensate for beam loading. The 5-MW output of the PA is transmitted to the Linac Tank through a 9-inch, 50-Ohm copper coaxial transmission line. The transmission line contains forward and reverse power monitors and a trombone for adjusting line length and reducing reflected power. A ceramic window (gas barrier) in the transmission line near the Tank isolates the accelerating cavity vacuum from the pressurized nitrogen gas in the line.

Cooling water is required for the 7835 filament and anode channels, the 4616 driver tube, the switch tubes, the filament power supply, and for the fan coil unit that provides chilled air to the modulator cabinet. Each RF station requires about 100 kW of electrical power.

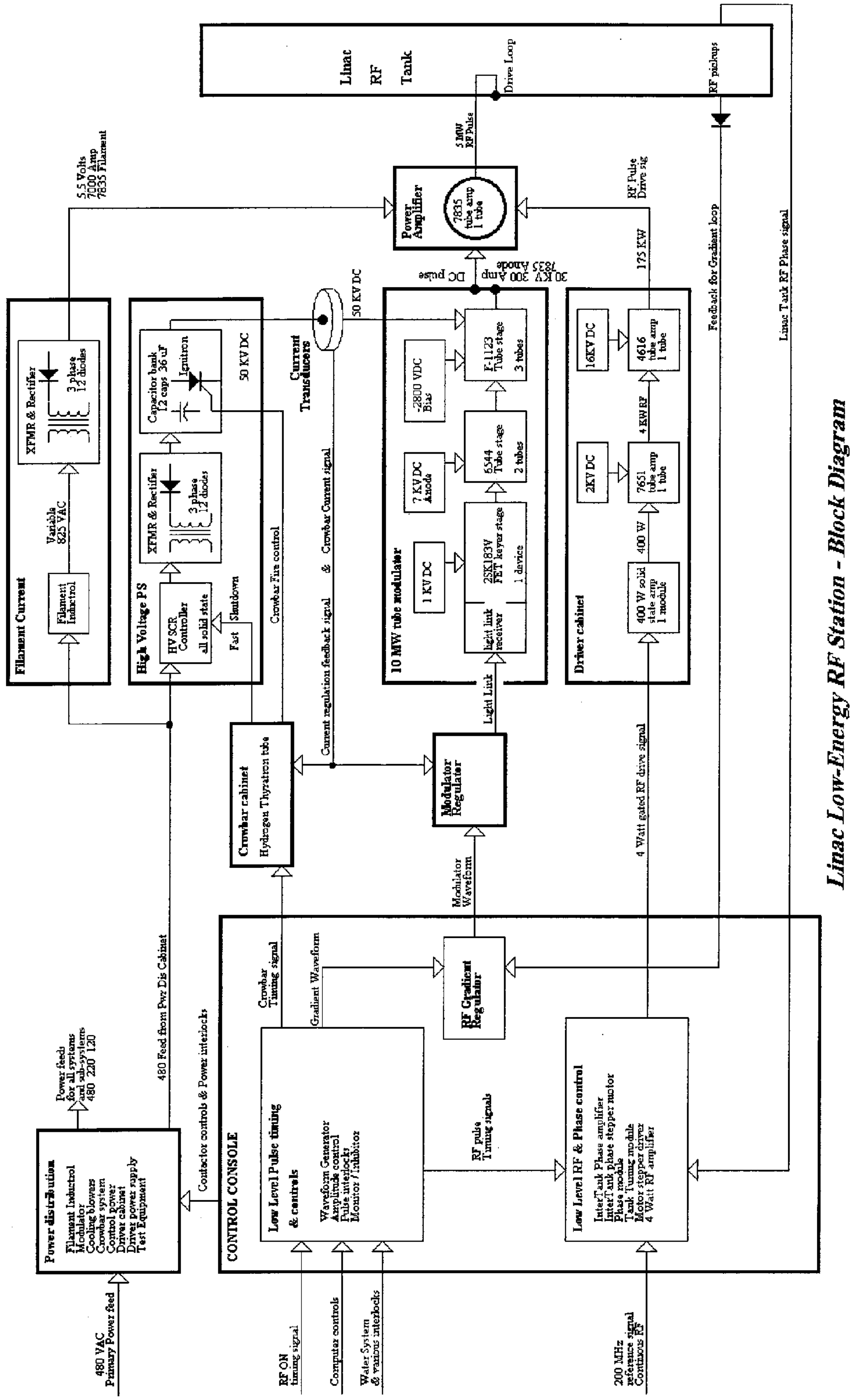

Figure 1. RF System Block Diagram

Status, Outlook, and Alternative Possibilities:

1. The Immediate Concern - Switch tubes

- **Present F1123 tube status**

Three F1123 "switch" tubes, electrically in parallel, serve as the high power series regulator element in each modulator to control the high voltage applied to the 7835 PA anode. The moniker "switch" is a misnomer, since the tubes are operated in the Linac modulators in a linear mode rather than simply as a fast switch. The modulator ramps up the anode voltage to turn on RF power in a controlled manner, provides active RF amplitude regulation and beam loading compensation during the pulse, and brings the RF voltage slowly back down. This method of anode voltage control minimizes large reflected power conditions when pulsing the stations. Linear operation of the switch tubes is a key element in the RF power regulation system. The switch tubes must be able to hold off 40 kV and to conduct ~100 A each (~300 A total).

Thirty years ago this tube was made by Westinghouse, then later ITT also began production. Westinghouse sold the tube rights and production equipment to Richardson Electronics who then sold them to Varian. Varian was later sold to CPI. CPI continued to make the tube until about two years ago, when they lost some of the fixturing for making the tube and also lost interest in continuing the product. In the meantime, ITT sold its interest to Triton who continued to make the tube.

Early in 2001, the U.S. Coast Guard, the major user of these tubes, determined that it would be 'upgrading its LORAN equipment and would only need one more production run of switch tubes.' That decision prompted Triton to announce that it would discontinue making the tube after one final production run. In response to these events, Fermilab ordered 50 tubes to provide adequate supply while pursuing alternatives.

Including the 200-MHz test station, Linac requires 18 F1123 tubes in operation. Records since 1995 show that about seven tubes a year are replaced. With 50 tubes on order, about 20 in-house spares, and even some allowance for duds, Linac's needs should be covered for a "grace" period of at least a five years within which an alternative must be worked out. To date, 15 tubes from the final order have been received and all have tested good.

- **Rebuilt tube possibilities**

Over the years Richardson, Econco and VTI have each tried to rebuild these tubes. None of the attempts were successful; no rebuilt tube came close to meeting required operational specs. Failures have ranged from an inability to complete the rebuild process to failure to meet high voltage hold-off requirements. Richardson recently attempted to have its French subsidiary make new tubes or process rebuilds, but this too failed.

Econco is once again trying to rebuild a tube. On their first rebuild attempt that tube failed to exceed 25 kV (40 to 50 kV is necessary). It was reworked and reached 35 kV; then additional HV conditioning was done in hopes of meeting specs. Latest Fermilab tests of that tube indicate that the effort may have finally been successful. Some hours of service in an operational station are yet required to confirm the achievement. Nevertheless, any long-term solution that relies on finding a competent tube rebuilder appears yet to be a high-risk plan based on past experiences.

- **Other tube possibilities**

200-MHz RF systems at Brookhaven and Los Alamos National Laboratories also have high power modulators driving 7835 PAs. In both cases, their series modulator tubes are significantly different from the F1123 and the tubes are operated as a fast HV switch, not as a linear regulator. The switch mode operation results in large reflected power peaks at turn-on and turn-off which causes excessively high and demonstrably damaging peak voltages in the PA and the transmission line systems. Several years ago, BNL upgraded its failing homemade 12-inch transmission line to a commercial 12-inch line because of this problem. Los Alamos uses a 14-inch transmission line to avoid breakdown due to high reflected power. The 9-inch lines in the Fermilab Linac are all the more susceptible to voltage problems, hence the necessary reliance on good RF power control throughout the complete RF pulse. To use a switch style modulator and tolerate operation at higher reflected power, the 9-inch lines would need to be replaced and/or circulators installed. This would be an expensive modification.

Los Alamos modulators use two Eimac 4CW100000D/Y647 tubes from CPI. The Los Alamos required RF power level is 3 MW as compared to our 5 MW per station. We would probably still need three tubes per modulator to achieve the necessary power. Some study of the applicability of this tube would be needed and could possibility be done at CPI. The ML8618 from Econco used at BNL, the ML7560 from CPI, and the Eimac/CPI 8973 tetrode are other possibilities to investigate.

Any change to accommodate a different tube would probably require a major physical rebuild of the modulator and modification of the modulator electronics. Hopefully a tube can be found that provides linear control, has commercial application, and will be in production for a long time. There are certainly no guaranties.

Continental Electronics has developed a tube modulator for the 7835 PA using a CPI 8973 tetrode. This is a very large tube and only one would be necessary as a replacement for the three F1123 switch tubes. Continental may be interested in designing and building just a HV floating deck section for the modulator using the 8973 to replace our current F1123 floating deck. They originally designed and built our present modulators. This appears to be a good option for the solving present problem, but it needs considerably more information and study.

2. Modulator System

- **Modulator status**

The three switch tubes, as discussed, are the major active component of the modulator. Controlling the grids of the switch tubes are two CPI-Eimac 6544 power tubes. The switch tubes are biased off by a DC –2.8 kV grid-to-cathode voltage supply and driven into controlled conduction by the 6544's. The 6544's are in turn controlled by a solid-state mosfet device. A fiber-optic line connects between the mosfet, at deck voltage, and the ground referenced low-level RF chassis. Signals to control the 7835 PA RF pulse and to effect beam-loading regulation follow this path.

The Eimac 6544 power tube made by CPI is a high production tube used in many low-frequency high-power systems. It is not expected that this tube will be discontinued.

The mosfet transistors are 15 years old but still available. Newer generations could be substituted if needed. Very few have failed since they were installed and several spare units and devices are in hand.

Several other tubes are required to regulate the DC bias voltages in the modulator. These are all small tubes available from several sources and other devices could be substituted with little difficulty.

- **High voltage capacitor reliability**

A large capacitor bank provides energy storage to supply the anode voltage pulse power. In each modulator, twelve three-microfarad capacitors (rated for 55 kV) are charged to 40 kV. The present capacitors were installed in 1996-97 to replace PCB capacitors used in the original design. Initially several of the new capacitors failed, but the failure rate has now decreased to about one per year. It is disconcerting that these capacitors fail at 40 kV since they were specified and allegedly designed and built for 55 kV. The failures have resulted in exploding HV insulators, ruptured capacitor cases, and in one instance a small fire which fortunately self-extinguished. An effort is currently underway to develop a new, more conservative, capacitor specification under which future capacitors will be ordered in an effort to obtain a more reliable product.

There is a fast crowbar system, consisting of an ignitron fired by a thyratron, to quickly discharge the capacitor bank when a PA tube spark occurs. The thyratrons are currently available and could be replaced, if necessary, with moderate system modification. The control circuitry for the crowbar system was replaced recently.

- **Reliability of other parts**

The HV charging supply for the capacitor bank has worked well. The rectifier stacks and the transformers have been very reliable and spares exist from the Linac Upgrade.

The modulator is cooled by air using a chilled water (55 degree) fan-coil cooling system. About two years ago the fan-coil heat exchangers were replaced after 30 years of service, so the modulator cooling is fine.

- **Replacement of the Modulator**

A PFN type modulator as used in the klystron systems could be adapted for the low-energy Linac. Continental has developed a solid-state modulator for the SNS klystrons and has stated that they could develop a similar solid-state modulator specifically designed for the 7835. Tentative layouts of the equipment fit nicely in the space occupied by the current modulator. However, this option would yield fast pulse rise and fall times, presenting similar reflected power, RF regulation, and beam loading feedback control difficulties as would a fast switch tube-type modulator. Control via the RF drive would need to be implemented in order to regulate the PA output, a situation to which the PA and the present driver are not well adapted.

Following an RF meeting with BNL, LANL and industrial representatives held during PAC2001, an engineer from Diversified Technologies, Ian Roth, spoke in favor of a solid-state modulator. He has since contacted Linac personal with an outline and sketch of his proposal. His scheme uses IGBT switches to turn on and off capacitors to form the ramp up and down and control the beam loading. This will keep the reverse power low. His ideas are interesting for a new modulator.

3. <u>7835 Power Amplifier</u>

- **7835 availability**

The Burle 5-MW 7835 power amplifier tube is an offspring of the 4617 tube designed as the original mate to the 300-kW 4616 driver tube. The 4617 contained oxide-coated filaments, whereas the 7835 incorporates thoriated-tungsten filaments for higher emission. These tubes were designed by RCA in the late 50's for the military's North Atlantic Radar System.

The accelerator community is now the only user of the 7835. This accounts for 20 active tubes and about five to ten new or rebuilt tubes each year. At 5 MW, this is the highest power 200-MHz tube available. Linac tank 4 requires 4.75 MW at 80 mA beam current (2.48 MW for cavity excitation and 2.27 MW to accelerate beam).

Tube rebuilding is a labor intensive operation. Rebuilding the 7835 remains profitable to Burle only because they continue to make and rebuild many other high power commercial and military tubes that require common equipment (lathes, presses, furnaces, etc.) and skilled individuals unique to these processes.

At this time we have assurances that Burle with continue to maintain the 7835. However, Triton gave us similar assurances about the F1123 less than a year before it was discontinued.

Note: In the 50's and 60's much of the equipment to develop and make these tubes was supplied to RCA by the military. Later when the military was no longer interested, the equipment became the custodial responsibility of Fermilab as it remains today. This represents some 30 major items that we maintain.

- **Replacement possibility - gridded tube**

Los Alamos has been working with a French manufacturer, Thales (formally Thompson), on a TH628 Diacrode tube to replace the three 7835 PA's for LANSCE. That Linac requires a maximum of 3 MW per tube with 10% duty factor. Their goal for the Diacrode is 3.5 MW, unfortunately our Linac cavities need 5 MW. Thales thinks the Diacrode may be able to make 5 MW, but their test stand is incapable of operating at that power level. They would presumably look for customer support to upgrade their test stand to prove the Diacrode to 5 megawatts. LANL might be in a position to make this test in a year or two, but there is no guarantee that they would.

In the mid 80's, Fermilab (Phil Livdahl and Curt Owen) with support from BNL contacted Varian-Eimac and Continental Electronics to do a study to develop a tube and cavity that would replace the 7835 PAs in use at Fermilab and BNL. The study concluded with Varian's paper design of the X2265 and Continental's investigation of an amplifier cavity. Prototypes were considered but never made. Since then Eimac was sold to CPI, who discontinued much of its glass-tube line including our switch tubes.

There is no known single-tube replacement for our 7835 PA. Multiple tubes operating in parallel are a possibility, although such a solution would present difficult phase and control complications. Any new tube developed at this power level would almost certainly be available from only a single manufacturing source and would be subject to continued concerns about availability. To implement a new PA tube would require complete replacement of the existing RF power systems.

- **Replacement possibility - klystron**

For Linac parameters of 201 MHz, 5 MW, 150 μsec, and repetition rate of 15 Hz a number of different klystron devices have briefly been investigated. Given the choices of limited gain, limited experience, or geometric size it is conceivable that a 200-MHz klystron device could be built. It could range in size from as long as 7.75 meters for a standard klystron to perhaps less than 4 meters for a multi-beam klystron. A klystron in many ways seems less risky than other devices and should have a very good lifetime and performance. With no experience in building a pulsed klystron at 200 MHz, significant development time and R&D money would be needed to realize such a design. Interfacing to the Linac cavity would need to be investigated.

Standard klystrons are large, cumbersome, and require much space; this makes multi-beam klystrons an attractive option. Possible specifications for a 10-MW multi-beam klystron, taken from a Muon Collider design study, are shown in Table 1. The 10-MW design is meant to achieve approximately 50% efficiency, but the klystron could most likely run at higher power with some reduction in efficiency.

Special attention would be required to keep the cost per klystron reasonable. This would involve trade-offs in the following areas: RF versus mechanical design in the gun region, the output window, the RF cavities, and magnetic focusing. It may be that the total lengths shown in Table 2, for a multi-beam klystron are not practical because of cavity coupling, geometry, or other mechanical constraints. The multi-beam option, nevertheless, has the potential of reducing the length considerably, which at least would allow the use of existing infrastructure in industry or other laboratories during the R&D

phase. It should be mentioned that this technology has been demonstrated to a certain extent (see for example the TESLA design report).

Peak RF Power Output	10 MW
Beam Voltage	~ 65 kV
Beam Current	~ 310 A
Duty Factor	0.23%
Rep Rate	15 Hz
Efficiency	~ 50%
Gain	~ 50 dB
RF output connection	14 inch diameter copper coax with EIA flange.

Table 1. Multi-beam klystron specification.

The corresponding modulator specifications are given in Table 3. With recent advances in high power solid-state electronics, insulated gate bipolar transistors (IGBTs) are a very attractive and cost effective solution for delivering high voltage to the klystron. Similar modulators with much longer pulse length have been built for the TESLA test facility. Solid state modulators have been built commercially for similar applications and are being considered for use in other high energy physics projects currently planned. Each klystron would have its own modulator (the HV power supply is included as part of the modulator).

Frequency, MHz		200	
RF Power, MW		10	
μPerveance , $A/V^{1.5}$		2	
Efficiency, %		44	
Item	Value	Value	Value
Type	ring	3 pole	2 ring+1
Number of beams	6	12	19
Vb	81	62	51
Itotal	279	368	442
Bz	233	251	264
Total anode diameter	53.3	58.4	60.9
l_q	6.201	5.279	4.759
Gun + collector length	1.05	0.87	0.77
Total length - from	2.6	2.18	1.96
- to	4.15	3.51	3.15

Table 2: Design envelope for a Multi-beam klystron

Courtesy of D. Sprehn, Stanford Linear Accelerator Center. Provided during working meeting on Feb.17th and 18th at Fermilab, Feb.2000, "Feasibility of Super-Conducting RF systems and Magnets for Muon Acceleration".

Voltage	65 kV
Peak Power	20 MW
Current	310 A
Average Power	60 kW
Pulse Width	200 μsec.
Size	1.2 x 1.2 x 2.4 meter
Rep Rate	15 Hz.
Droop	~ 5%

Table 3. Solid State IGBT Modulator specifications.

A klystron solution might be attractive if a large number of similar devices would be needed for a future project (e.g. Muon Collider) so that the high initial R&D costs would be spread over many units. It is probably not practical to think of developing a 5-MW 200-MHz klystron for only 5 stations.

4. Driver

- **4616 availability**

The Burle 4616 is still used extensively by the military. They seem to order 50 to 100 per year. This tube along with many similar tubes used commercially and militarily keeps the Burle power tube line going. At this time, there is no indication of Burle discontinuing this tube or the other tubes we get from them.

- **Status of other tubes and parts**

The driver uses a 6544 to pulse the screen voltage of the 4616 driver tube. In this application the tube gets light duty and has a long lifetime compared to the two 6544's in the modulator.

The first RF tube stage in the driver is a 4-kW Burle 7651. This tube is relatively small and used in many commercial applications. It should remain available or could be replaced with other tubes or solid-state devices if necessary.

The 4616 anode supply crowbar circuit utilizes a 7703 ignitron. It is expected that this tube will remain available or could be replaced in a straightforward way if needed.

- **Replacement of the driver system**

The future of the driver stations does not appear to be in jeopardy. The driver is a mate to the 7835 PA and they operate well together. We have several spare driver stations as a result of the Linac Upgrade.

Argonne recently investigated obtaining from Continental Electronics an "identical" driver station to ours. The estimated price was $1.3M for one unit.

5. Complete upgrade of low-energy stations

- **RF systems**

Complete replacement of a low-energy Linac RF station is a large and expensive program. It is only necessary or desirable should the 7835 PA tube become unavailable. In that case, there are few options:

1. BNL and Fermilab may need to buy the rights to build the tube and do the job in-house or contract the work out. BNL has already spent considerable time understanding the tube in order to make the rebuild of the tube more reliable. They may have the knowledge for rebuilding or producing the tube. It must be realized that BNL is becoming less dependent on its Linac and this might not be in its interest in the future. SLAC has a tube manufacturing facility, mostly for its klystrons, and might consider building the 7835.
2. Convince a manufacturer (Thales for example) to design and build a 200-MHz, 5-MW tube and build new RF stations.
3. Use two Thales TH628 Diacrode 200-MHz tubes for Linac cavities 2 through 5; only one is needed for tank 1 (9 total for the five tanks). Parallel tube operation presents the difficulty that each PA must work in phase and amplitude with its counterpart to drive the tank. The power could be fed through separate inputs, ports for which exist in the Linac tanks, or the power could be combined in the gallery and utilize the present transmission line and single cavity drive input. Handling of the RF power would need careful investigation. This option requires having two complete 2.5-MW stations where presently there is one 5-MW station. Space, operation, maintenance, etc. would all become more serious problems.
4. Change to 200-MHz klystrons. These would need to be developed, they would be large and expensive, and complete new stations would need to be built around them. This option appears to be prohibitively expensive.

- **New Low-Energy Linac (400 MHz?)**

An alternative to replacing the 200-MHz RF power systems for the existing accelerating structures is to build a new drift-tube Linac operating at 400 MHz. Many more 400MHz klystron-like devices are available than 200-MHz devices. Also the klystron devices have a longer lifetime and better reliability than high power tube equipment. The Spallation Neutron Source low-energy Linac at ORNL will be based on 400-MHz systems, as likely will other future Linacs. Such a Linac could be a decided improvement over the existing machine in terms of both beam performance and system maintainability. The present low-energy Linac is aging and needs significant improvement in many areas, not just the RF power systems. In its present enclosure, it will become limited by radiation considerations as higher intensities, higher average beam pulse rate (5 or 7.5 Hz), and longer pulses are expected.

Summary

The immediate problem is the modulator switch tube that is being discontinued by the last remaining manufacturer. Fermilab should have, if all goes well, a five or more year supply of these tubes. Finding new suppliers to make or rebuild these tubes seems to be an uncertain possibility. Discovering a replacement tube type that could be retrofit into the modulators is an option, but much work will need to be done to identify and test such a solution and then to modify all the modulators and associated components. There is a chance that one manufacturer might be interested to design and build a replacement HV deck for the modulator or build a whole new 7835-compatible modulator. Even after over-coming the switch tube problem, the modulator systems remain vulnerable to the demise of other tubes. Replacing the modulator with a solid-state unit is a remote prospect that may be accompanied by transmission line and RF control complications.

Beyond the modulator, further replacement of the 200-MHz RF stations becomes decidedly more difficult, costly, and lead-time critical. Presumably, only the 7835 PA tube becoming unavailable would drive this. In that case, the next logical step may well be to replace the low-energy drift-tube Linac with a new 400-MHz Linac in a new enclosure. A similar conclusion may be reached from other arguments based on the mechanical and electrical aging of the 30-year-old Linac Tanks, drift-tube quads, water systems, etc.

No easy or inexpensive solution exists for solving the potential low-energy Linac RF problems. On March 1, 1971 the Linac plant cost totaled $12,165K, not including tunnel construction. RF power system costs were $4,049K (~1/3) of that total. Trying to use DOE escalation tables from 1971 to present, the inflation factor is about 5. Thus the 200-MeV Linac cost would be $60,825K today and, of that, the cost for 10 RF stations (9 plus spare test station) would be $20,245K. The present low-energy Linac (with test stand) requires only six RF power stations indicating an estimated replacement cost of ~$12,000K plus overhead and other costs.

Conclusion

Any reasonable plan for dealing with Linac RF power system concerns should be based on the service life expected from the 200-MHz Linac. Plans for three different service-life "time horizons" of the 200-MHz Linac are presented from a RF power system perspective, ignoring the frailties of other 30+ year-old Linac mechanical and electrical systems.

1) Five to Seven Year Service Life Horizon

The current 200-MHz Linac is expected to serve planned Run II, MiniBooNE, NUMI, and SY120 type operations until LHC turns on in 2008. In this case, the appropriate path would appear to be continuation of the status quo. Switch tubes on-hand should support strong operation for 5-7 years after which time the 200-MHz RF power systems and present Linac limp into oblivion.

The biggest uncertainty and greatest risk from an RF power equipment point of view in this plan is the viability of the 7835 PA tube. A 2-3 year spare supply, six to eight of these PA tubes should be accumulated early in this time frame. (We currently have one good spare, one in limbo, and two in the rebuild process.) Constant vigilance of 7835 prospects is important.

2) Eight to Fifteen Year Service Life Horizon

The current 200-MHz Linac is expected to run strongly and reliably through delayed LHC turn-on and through BTeV. This time frame remains too short for pay-off of a new 200-MHz power amplifier design. Efforts in the first two years, starting now, should focus seriously on identifying and qualifying a rebuilder for the F1123 switch tubes. Should that effort fail, energies must then immediately turn to a modulator redesign/rebuild program, probably with assistance from qualified industrial concerns. A serious three to four year program costing roughly $3 to 4 million (WAG) should be sufficient to bring on-line six upgraded modulators for the 7835 PA in 2008 or 2009.

Again and ever more so, this plan's greatest RF power equipment risk is the viability of the 7835 PA tube. A 2-3 year spare supply of these tubes should be accumulated and maintained early in the time frame of this plan and grown to a five year supply (12-15 tubes) by the eighth year. Constant vigilance of the 7835 is critical, lest this plan fall short of its goal by as much as several years!

THIS PLAN APPEARS TO BE WITHIN THE SCOPE OF PRESENT PROTON SOURCE MANAGEMENT AND IS TAKEN AS THE DEFAULT PLAN.

3) More than Fifteen Year Horizon

It seems extremely unwise to rely on the 200-MHz Linac for more than 15 years from the present. If Fermilab requires a viable H^- or proton Linac beyond that time, plans should focus on defining those beam requirements as soon as possible and then getting on with the business of design, approval, and construction of a new machine. The current Linac can be operated within one of the above short-term plans that would be appropriately modified to optimize operational cost effectiveness in view of the schedule of the new machine. A goal should be to realize and take advantage of the benefits of the machine as early as possible.

The greatest dangers to future Linac operational viability are failure to decide upon and actively pursue some plan or to lose sight of that chosen plan. The outcome in such case is almost certainly the demise of a reliable Linac and the unavailability of protons to serve Laboratory objectives.